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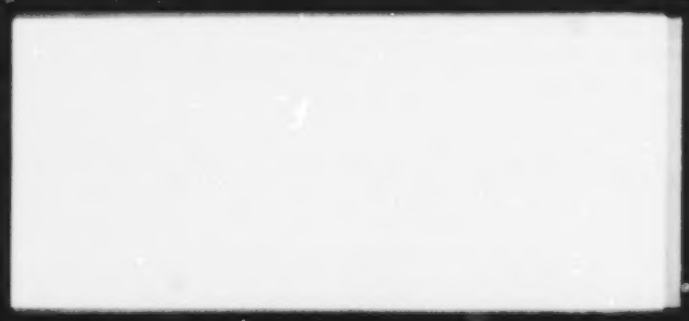

BC

MINISTRY OF
ENVIRONMENT
AND PARKS

PROVINCE OF BRITISH COLUMBIA
MINISTRY OF ENVIRONMENT AND PARKS

ACID RAIN IN BRITISH COLUMBIA

April 1988

1.0 INTRODUCTION

In the late 1970's, governments in western Canada became concerned about the potential impact of atmospheric pollution arising from increased industrial activity in western Canada and the United States. The four western provinces agreed in 1980 (Northwest Territories in 1982) to work together to develop the basis for sound management of the atmospheric pollution problem. In the years since this agreement there has been coordinated monitoring and research into atmospheric pollutants, including those that cause "acid rain." The coordinated effort in western Canada includes the collection of data on the rate of deposition of sulphate in precipitation, emission inventories to identify sources of acidic gases, mapping of the sensitivity of terrestrial and aquatic systems to acidic deposition and testing of better models to describe the transport of atmospheric pollutants in western Canada.

2.0 ACIDIC DEPOSITION

The term acid rain is today a household word in most industrialized countries, yet 15 years ago it was familiar only to a few environmental scientists. Some constituents of air pollution are acids or become acidic when they reach the Earth's surface and interact with water, soil, or plant life. The deposition phenomenon is commonly referred to as acid rain even though the pollutants may be deposited in wet or dry form (Figure 1). Wet deposition encompasses all processes by which atmospheric pollutants are transported to the Earth's surface in one of the many forms of precipitation (eg. rain, snow, or fog). Dry deposition includes both gas and particle transfer to surfaces exposed to the atmosphere and represents all pollutant material that is not collected by wet only deposition.

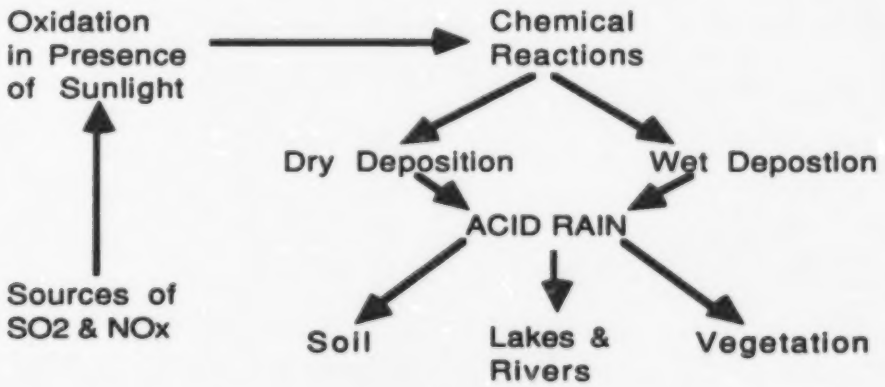

Figure 1: Simplified Schematic of Acid Rain Cycle

The major emissions affecting the composition of acid rain are oxides of sulphur and nitrogen. Gaseous and particulate sulphur and nitrogen emitted into the atmosphere may be deposited in a dry state near the source within a day. As the gaseous components are oxidized to acid, the time they potentially spend in the air becomes longer, ranging up to several days. This means that a substantial portion of the acidifying air pollutants is transported by the winds hundreds or even thousands of kilometres from the source of emission. Because the wind direction changes, air pollutants emanating from one place will be carried away to many different points of the compass, increasing the possibility of acidic deposition far removed from the pollution source.

2.1 EMISSIONS OF SULPHUR DIOXIDE

The south coastal area of British Columbia is affected by a variety of industrial point source emissions of acidic pollutants. The sulphur dioxide emitted on a daily basis from industrial sources in British Columbia and Washington State are presented in Figure 2a. On Vancouver Island, most of the emissions of sulphur dioxide originate from six pulp mills. In the Lower Mainland , nine companies emit the majority of sulphur dioxide. Of these, four are petroleum refineries, two are cement plants and three are pulp mills. In the northern coastal region, three plants emit sulphur dioxide, the largest source being the aluminum smelter at Kitimat. The major sources of sulphur dioxide emitted in Washington State are thermal power plants, petroleum refineries, aluminum smelters, pulp mills and cement plants.

Other, generally smaller, sources of SO_2 include residential heating and internal combustion engines. Figure 2b illustrates total sulphur dioxide emissions for each regional district in British Columbia and county in Washington, including point and all other area sources.

2.2 ACIDIC DEPOSITION MONITORING

Since mid 1987 there have been 13 stations monitoring acid precipitation in British Columbia. Eight stations are located in the Strait of Georgia area while the remaining five are scattered throughout the southern half of the province as shown in Figure 3. The precipitation acidity is measured in terms of pH or hydrogen ion concentration. A decrease of one unit in pH indicates a ten times increase in acidic concentration. As well as monitoring acid precipitation, these sites provide data on wet sulphate ($SO_4^=$) deposition rates on a weekly basis. The wet sulphate is derived from sulphur dioxide (SO_2) introduced into the atmosphere, which is oxidized in the presence of water vapour to become sulphuric acid. The average pH and total sulphate data from 1986 for several British Columbia stations are presented in Figure 4a and 4b.

In general, pH values are lower and $SO_4^=$ values higher at coastal sites in British Columbia. This difference is due to a higher density of sulphur dioxide sources in coastal areas and an increased concentration of calcium ions (Ca^{++}) at interior stations derived from the calcium-rich soils of that region. In the interior, particles of calcium sulphate become airborne and provide a means of neutralizing, or "buffering", the effect of acids present in the atmosphere.

2.3 TRANSPORT OF ACIDIC POLLUTANTS IN COASTAL BRITISH COLUMBIA

An understanding of the atmospheric transport of pollutants is necessary to explain the variability observed at precipitation chemistry monitoring locations. To trace the origin of an air parcel associated with a precipitation event, back trajectory analysis is done using parameters such as the storm track, orientation and speed of movement. These data can be used to estimate the source of the sulphate ($SO_4^=$) ions present in rain samples.

Meteorological conditions affecting pollutant transport in the southwest coast region of British Columbia and Washingtion can be divided into a wet period lasting from fall to late spring and a drier period during the summer months. Over 75 percent of the average annual precipitation (snow and rain) falls between October and April. These storms, which can deposit acid rain, are associated with the passage of frontal systems and contribute to the scavenging of pollutants.

Figure 2a - Point Sources of Sulphur Dioxide in
Coastal British Columbia and Western Washington

Figure 2b - Sulphur Dioxide Emissions in British Columbia and Washington

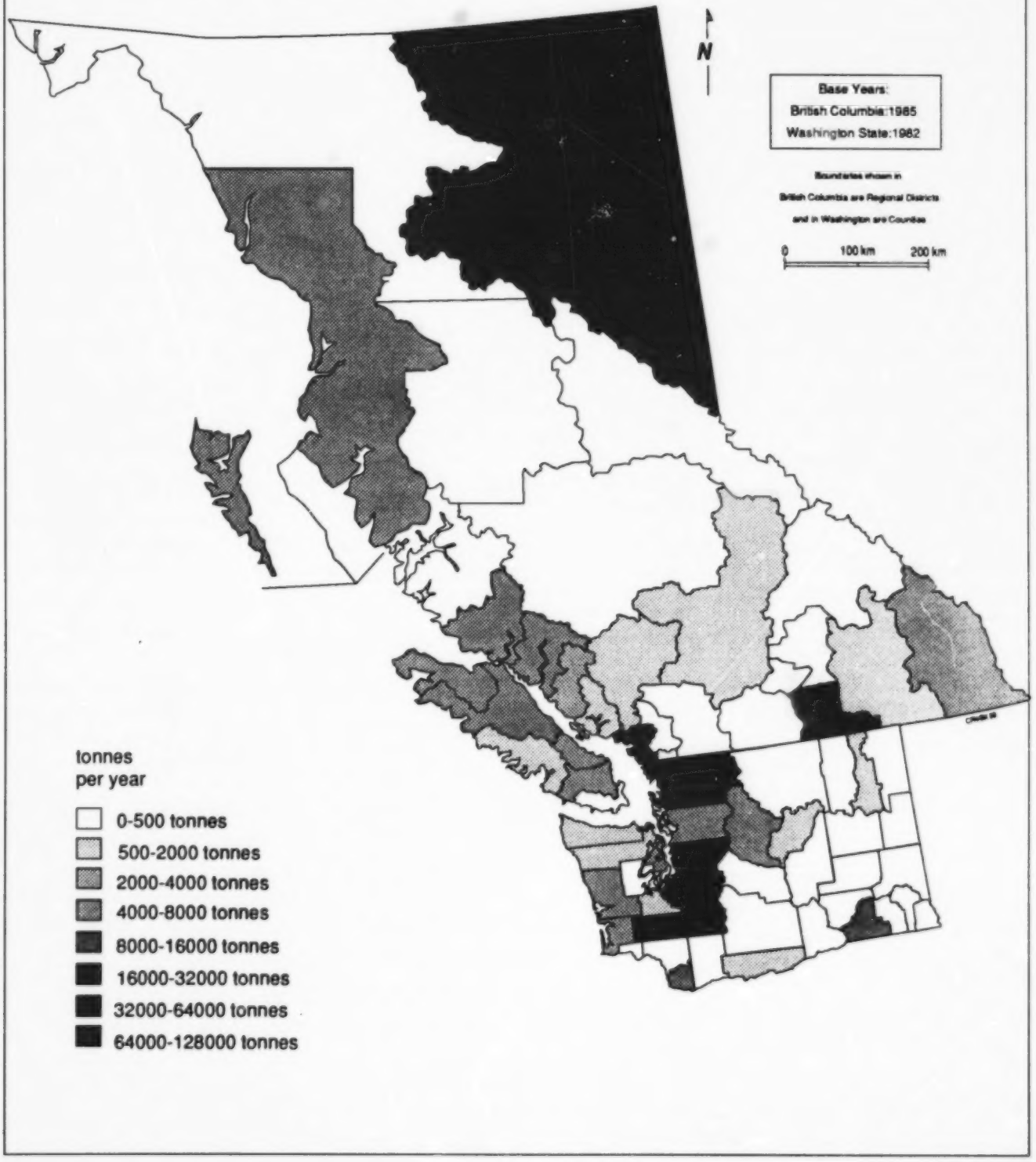

Figure 3 - Precipitation Chemistry Stations in British Columbia

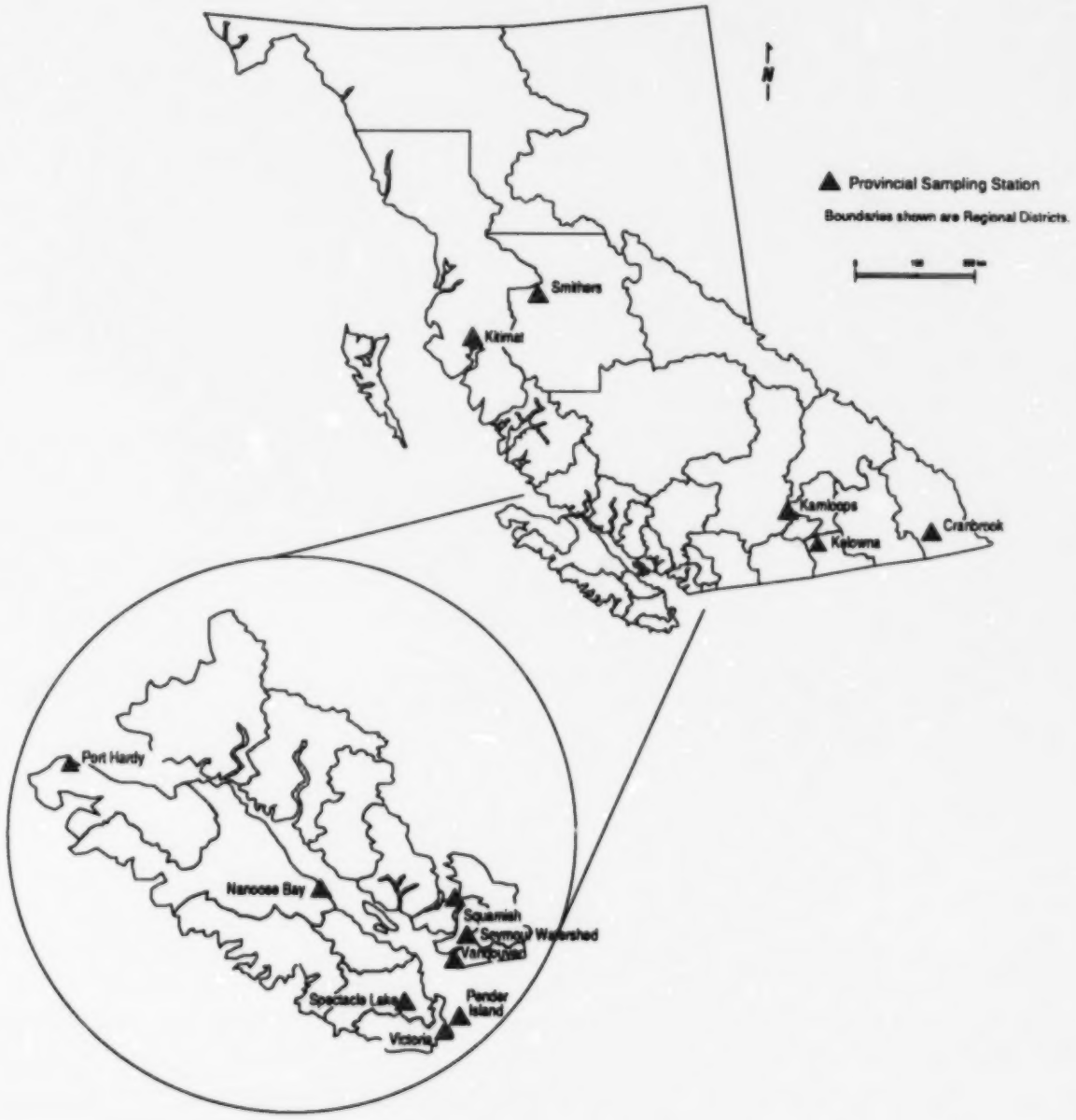

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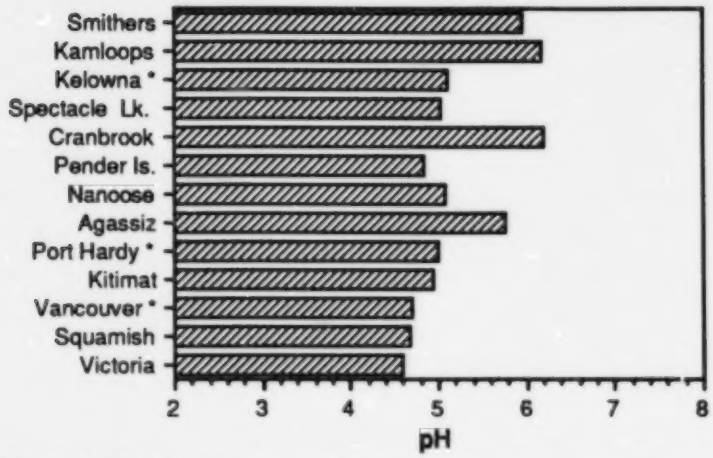
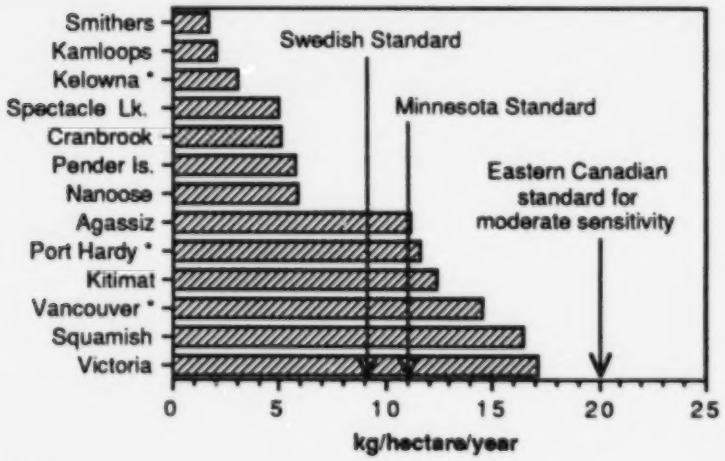
Figure 4a - Acidity of Precipitation in British Columbia



Note: * indicates 1985 data

Figure 4b - Sulphate Deposition Levels in British Columbia



Note: * indicates 1985 data

Three typical storm trajectories that affect the Lower Mainland are flows from Oregon and Washington, flows down the coast from the Gulf of Alaska, and outflow conditions from the interior of the province. All three of these situations introduce pollutants in varying amounts from a variety of sources. Normally, during a winter precipitation storm event, winds affecting pollutant transport are southerly in the Georgia Strait and easterly in the Strait of Juan de Fuca. Such trajectories will transport source emissions from Puget Sound into the Lower Mainland area. Flows from the Gulf of Alaska moving down the coast will often introduce acidic

ions from Vancouver Island and Lower Mainland industrial sources into the south coastal area of British Columbia. Outflow conditions, associated with high pressure systems located over the interior of the province, import few sulphate ions to the Lower Mainland and in addition are often accompanied by strong winds which tend to dilute the air mass. The topography of the area has a profound influence on these storms affecting both the precipitation amounts and low level winds.

During summer and fall, dry periods can be of considerable duration, and dry deposition is the dominant form of acidic deposition. Light winds and suppressed vertical transport allow a large burden of pollution to build up in the area. This build up will eventually be scavenged by the next storm to precipitate in the region.

Dry deposition is a poorly understood component of acid rain in British Columbia. Recent studies indicate that dry deposition varies from three times wet deposition near sulphur sources to one-third of wet deposition at locations far removed from sources. The Ministry of Environment and Parks will be initiating a program to measure dry deposition in the Lower Mainland in 1988.

Recent research has indicated that acidic contaminants in fog can also contribute to deposition levels. To assist in understanding the contribution of fog to the problem of acid rain, a pilot project monitoring fog water chemistry has been initiated on Mount Seymour, near Vancouver. This project is a critical step towards understanding the complexities of fog chemistry on high altitude ecosystems in southwestern British Columbia.

2.4 OZONE

Ozone is an important constituent of acid rain, rapidly oxidizing sulphur dioxide and nitrogen oxides (NO_x) in the presence of sunlight into sulphuric and nitric acid respectively. Peak ozone air pollution levels in the Lower Mainland are among the highest in Canada, and during the summer regularly reach the range where the health of sensitive individuals may be affected and damage may occur to agricultural crops and other vegetation. Based on preliminary estimates, hydrocarbon emissions, a major contributing component in ozone production, must be decreased by between 30% and 70% in order to reduce peak ozone levels to within the national acceptable air quality range. Light-duty motor vehicles are the largest source of emissions causing ozone pollution in the Greater Vancouver/Lower Mainland area, contributing about 35% to the total hydrocarbon emissions and about 25% to the total NO_x emissions.

The Ministry of Environment and Parks, in cooperation with the Greater Vancouver Regional District and Environment Canada, is currently evaluating control option strategies. Work underway includes monitoring ozone levels at 22 stations, evaluation of meteorological conditions that influence ozone episodes, a detailed inventory of stationary, area and mobile sources of pollutants contributing to ozone levels, an inventory of hydrocarbon emissions during gasoline marketing and development of costs for controlling these emissions, modelling source impacts on ambient air quality and evaluation of ozone impacts on public health and vegetation.

3.0 THE EFFECTS OF ACID RAIN

The acidification effects depend on two factors: the amount of the wet and dry deposition, and the sensitivity of the soil, vegetation, and lakes and streams to acidification. The earliest effects become apparent where there is the most unfavourable combination of deposition and sensitivity.

3.1 SOILS AND GEOLOGY

Acidic deposition on the land surface is altered by various reactions as precipitation runs over the land or moves into the soil. Ultimately, streams and lakes which receive drainage waters will be affected by reactions which occur in the watershed. Agricultural crops and other vegetation growing on soils receiving acidic deposition can also be affected by reactions which alter the soil. Sensitivity of soils to these and other changes varies with the nature of the soil.

Two British Columbia sensitivity maps rating soils and geology for impacts of acidic deposition have been prepared (Wiens et al., 1987). The first illustrates the potential of soils and geology to reduce the acidity of precipitation and thus the effects on drainage waters to lakes and streams. The second illustrates the susceptibility of soils to chemical changes which could affect plant growth.

These maps show high potential to reduce acidity in Rocky Mountain and foothill areas, central British Columbia areas with soils developed in fine textured materials, and alkaline soil areas in the southern interior. Extensive areas with low potential are found in mainland coastal British Columbia and the west coast of Vancouver Island as well as central, northern, and southern mountainous areas.

Areas with ratings of high soil sensitivity to acidic inputs are extensive in western coastal and mountainous areas of northern British Columbia and the West Kootenay region. Low sensitivity ratings are restricted largely to interior valleys and fine textured soils.

3.2 VEGETATION

Forest die-back, crop damage and vegetation injury from air pollutants are occurring rapidly and on a large scale in many of the developed areas of the world. In Western North America air pollution damage and forest decline are as yet more subtle and localized.

Ozone affects vegetation directly by reducing growth, causing injury and damage to leaves. Injured trees are weakened and may become a ready target for insects and fungal diseases. Acid rain may impact on ozone injured leaves and wash out essential minerals, causing additional stress. The nitrogen component of acid rain has been implicated in delaying frost hardiness, increasing the risk of frost injury. The acidification of the rooting zone of the soil may result in metal toxicity, reducing root growth or affecting the beneficial cooperation between roots and fungus. This may directly or indirectly reduce the ability of plants to cope with drought, and reduce their ability to take up nutrients from the soil.

Relatively little is known about the sensitivity of most trees in western Canada to major atmospheric pollutants. The Ministry of Environment and Parks is involved in studies including the effects of air pollution on forest seedlings, the effects of air pollution on forests of the Puget Sound, the use of remote sensing techniques to evaluate SO_2 damage to tree growth on northern Vancouver Island, the effects of SO_2 on alpine lichens, dose/response of agricultural crops, and the effects of acid rain on soils and vegetation.

3.3 AQUATIC ENVIRONMENTS

Surface waters are among the first to show impacts caused by acidic deposition. Since 1981, British Columbia has studied aquatic sensitivity to acidic inputs to gain sufficient knowledge about the aquatic environment so that a management strategy could be developed to protect sensitive systems. New water quality data were collected and have been used to prepare lake sensitivity maps (Swain, 1987).

The five water quality characteristics of concern (pH, aluminum, alkalinity, calcium, and magnesium) were monitored. Maps which define lake acidity were based on pH data and lake sensitivity maps were prepared using alkalinity and calcium data. The sensitivity maps prepared for each of calcium and alkalinity were then overlaid to produce a generalized lake sensitivity map. Areas were classified on the generalized lake sensitivity map by using the rating which indicated the higher sensitivity from either the calcium or alkalinity maps. By the end of 1987, information had been obtained for about 800 lakes, or about 3.6% of the estimated 22,000 lakes in British Columbia.

To determine whether acidic inputs are causing a significant trend in the deterioration of water quality at sensitive lakes, six lakes on Vancouver Island, Saltspring Island, and in the Lower Mainland are monitored monthly. Analysis includes pH, alkalinity, acidity, general ions, metals, biological components and lake sediments. The program began in 1984, and data are to be analyzed once a minimum five year data set is available.

The mapping indicates that lakes within about 250 km from the west coast, on Vancouver Island and the Queen Charlotte Islands, and at several other scattered but considerably smaller areas, are classed as being either of high or moderate sensitivity. These scattered areas are near Atlin Lake, north from Stuart and Shuswap Lakes.

3.4 SENSITIVE ENVIRONMENTS

A combined map of environments that are sensitive to acidic deposition was produced based on the soil and geology maps and the aquatic maps and is presented in Figure 5. This composite map portrays **the most sensitive environments in the Province** resulting from overlaying the potential of soils and geology to reduce acidity and the lake alkalinity map. The most sensitive areas, indicated by classes 1 and 2 on this map, are found in coastal region of British Columbia. This is also the area with the major source emissions.

4.0 ENVIRONMENTAL PROTECTION AND ACIDIC DEPOSITION

Ideally regulatory limits would be based on soil chemistry, plant physiology, water chemistry, terrestrial and aquatic ecology, but this type of information is currently not available. Soil chemistry would be an ideal representative; it is the predominant factor in water chemistry in most drainage basins, and hence is a major factor in the well-being of forest and aquatic ecosystems. However our understanding of the complex interrelationships between soil and water chemistry is rudimentary, and limits to the rate of acidic deposition based on soil chemistry are not practicable. The chemistry of surface water reflects the chemistry of the soils and geology in the basin, therefore water chemistry provides a convenient foundation of environmental standards to protect all ecosystems of the basin.

Aquatic ecosystems are among the first to show measurable changes when acidic deposition increases beyond an acceptable limit. Changes in the distribution and abundance of aquatic organisms can provide immediate evidence of the impact of acidic deposition. Among the most vulnerable animal species are invertebrates, like mollusks, which have an outer shell made of calcium. Increased acidity of the water reduces the availability of calcium, and increases the metabolic cost for an organism to obtain it.

Fish are among the least sensitive organisms in an aquatic ecosystem; by the time conditions have deteriorated enough to affect the fish many other kinds of environmental damage will have occurred. Nevertheless, damage to fisheries populations caused by acidic deposition is known to have occurred elsewhere in the world. Conditions known to cause environmental impact can help to define safe limits to the rate of acidic deposition in British Columbia. In eastern North

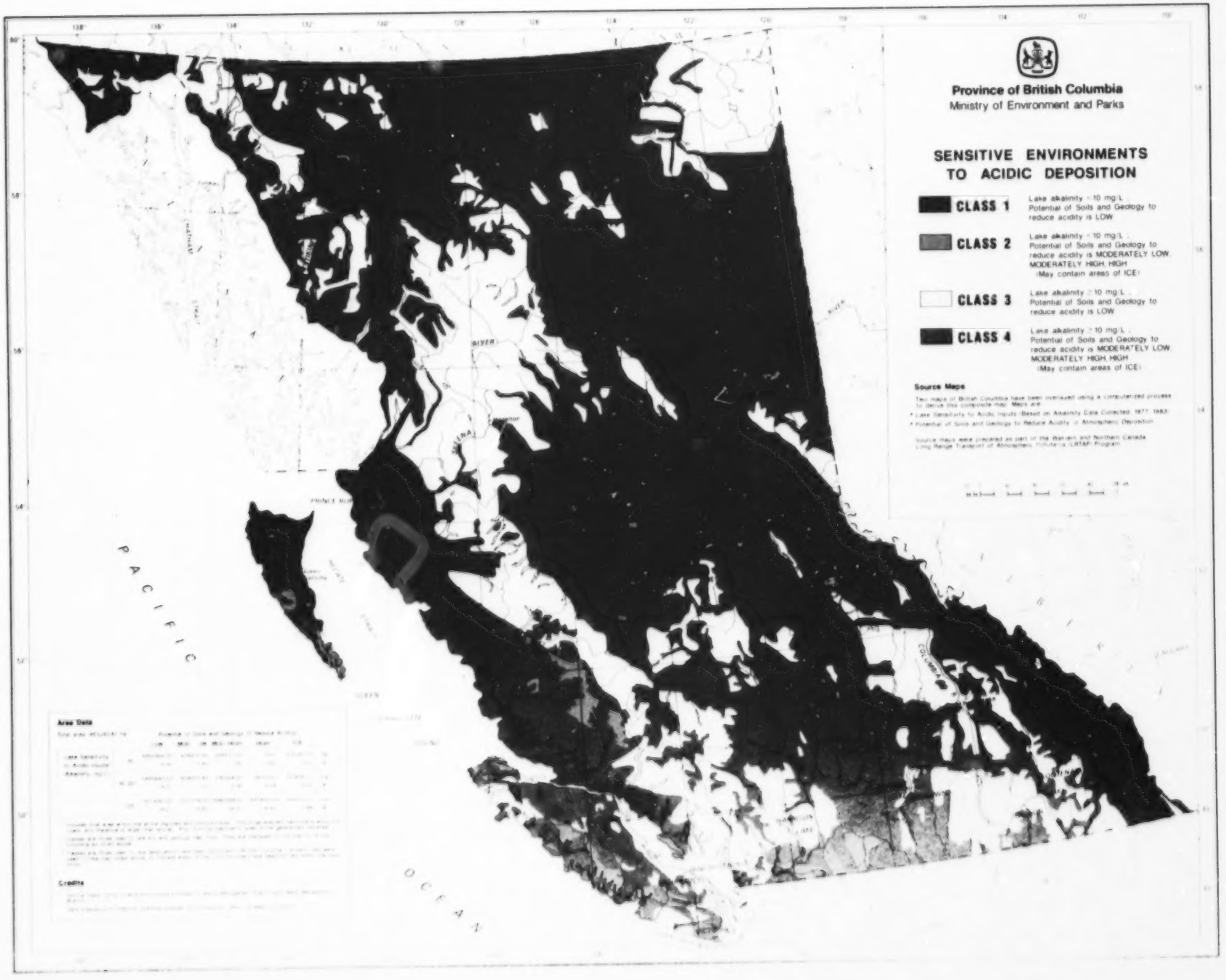
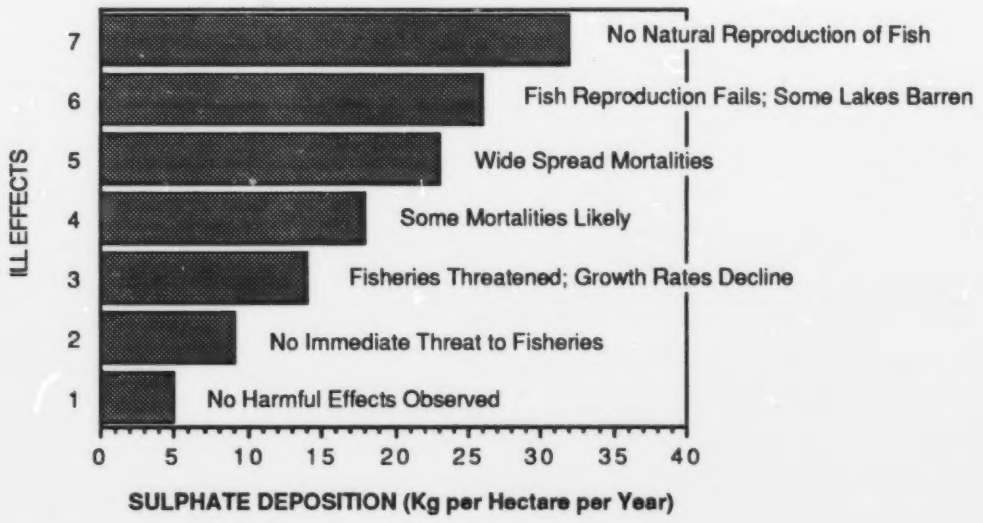

Province of British Columbia
Ministry of Environment and Parks
SENSITIVE ENVIRONMENTS
TO ACIDIC DEPOSITION
CLASS 1
Lake alkalinity < 10 mg/L
Potential of Soils and Geology to reduce acidity is LOW
CLASS 2
Lake alkalinity < 10 mg/L
Potential of Soils and Geology to reduce acidity is MODERATELY LOW, MODERATELY HIGH, HIGH
(May contain areas of ICE)
CLASS 3
Lake alkalinity ≥ 10 mg/L
Potential of Soils and Geology to reduce acidity is LOW
CLASS 4
Lake alkalinity ≥ 10 mg/L
Potential of Soils and Geology to reduce acidity is MODERATELY LOW, MODERATELY HIGH, HIGH
(May contain areas of ICE)
Source Maps
Two maps of British Columbia have been overlayed using a computerized process to derive this composite map. Maps are:
• Lake Sensitivity to Acidic Inputs (Based on Alkalinity Data Collected 1977-1983)
• Potential of Soils and Geology to Reduce Acidity of Atmospheric Deposition
Source maps were prepared as part of the Western and Northern Canada Long Range Transport of Atmospheric Pollutants (LRTAP) Program
PACIFIC
OCEAN
Area Data
Credits

Figure 5

America, increased rates of acidic deposition put fisheries resources at increased risk and the environmental impact of acidic deposition in vulnerable aquatic ecosystems escalates steadily as shown in Figure 6.

Figure 6 - Ill Effects of Acidic Deposition to Fisheries in Vulnerable Ecosystems



These impacts, although they occurred in eastern North America, possibly apply to moderately sensitive lakes in British Columbia. There are indications that sulphate deposition less than 9 kilograms of wet sulphate per hectare per year (kg $SO_4 = ha^{-1}yr^{-1}$) is not immediately harmful to most fisheries; however extremely sensitive aquatic systems would not necessarily be protected by a deposition rate of 9 kilograms. Spring is a particularly vulnerable time of year for fisheries because many species spawn. Streams, for example, might need protection from high rates of acidic loading during periods of snow-melt when sulphate, trapped in the winter snowpack, is suddenly released.

Regulatory limits to the rate of acidic deposition must be set in conjunction with what is known about the sensitivity of the environment. From this point of view the Western LRTAP Committee commissioned a study by the National Research Council to assist the development of target loadings for western Canada (Western and Northern Canada LRTAP Technical Committee, 1987). (***Loadings*** are a measure of the rate of acidic deposition; ***target*** refers to a regulatory limit). Although this study does not recommend specific target loadings that could be used to regulate sulphur emissions in British Columbia, it does suggest a model to protect aquatic ecosystems. Further research would be required to develop this model such that it could be applied, and to develop limits to protect terrestrial ecosystems as well. The Committee is currently evaluating target loadings to be used in western Canada.

5.0 ACTION PLAN

The Ministry of Environment and Parks will continue to work on atmospheric modelling of sources of sulphur and deposition impacts on the environment. This would involve maintaining an inventory of emission sources, continuing to operate a precipitation chemistry network to evaluate deposition patterns, investigating the role of dry deposition and fog water chemistry

impacts, and evaluation of the effects of acidic deposition on the environment, particularly on forests and fisheries.

The Ministry is reviewing sulphur sources that are permitted under the Waste Management Act in British Columbia to ensure that acidic deposition levels are within acceptable limits to provide protection to sensitive ecosystems. Where there is a reason to do so, permits may be amended. Although British Columbia produces a substantial amount of acid forming emissions, there are also emissions from Washington that are carried into British Columbia that need to be considered and their impacts evaluated. A new federal monitoring station, planned for the Gulf Islands, is anticipated to provide daily information that would be used to study exchanges of acid rain across the international border.

Through early attention to even the most sensitive ecological systems, the Ministry of Environment and Parks is confident that British Columbia's environment will be well protected from the detrimental impacts of acidic deposition.

6.0 REFERENCES

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